

Application of Coordinate Measuring Technique in Hot Cell

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Abstract: The research presented here focuses on dimension measurement of nuclear fuels or materials in hot cell using coordinate measuring machine (CMM), which was structural adjustment to adapt hot cell environment. The automatic measurement was achieved by means of using coordinates to establish position and sectional measuring with special fixture. Experiment measurements involving the thickness of plate-type fuel element (FE), the diameter and ovality of tubular fuel element, shape dimensions of fuel assembly (FA), and other dimensions. The research results showed that coordinate measuring technique could be applied in hot cell for post irradiation dimension measurement, which applied to measure different dimensions with a high measure precision of $2\mu\text{m}$.

Keywords: coordinate measuring technique; hot cell; automatic measurement; FE; FA

1 Introduction

The growing operational requirements for nuclear fuel or material, such as longer fuel cycles, higher burnups and wider use of transient regimes, require more robust fuel designs and more radiation resistant materials [1-3]. Development of such advanced fuels and materials is only possible with testing and analysis of their performance and application of adequate post-irradiation examination (PIE) methods and techniques [4-7]. One major goal of PIE is to answer the dimension change of nuclear fuel or material before and after irradiation. The hot cell has then started to adapt or develop new specific dimension measure methods for radioactive materials.

Coordinate measuring machine (CMM) is a new precision measurement instrument with a measure precision higher than $2\mu\text{m}/1000\text{mm}$ in latest 30 years, which always a computerized inspection device for gathering discrete point data and analyzing dimensions and tolerances [8-11]. The coordinate measuring technique has revolutionized the inspection of manufactures parts throughout manufacturing and has played a critical role in the globalization of manufacturing in past decades because of its high measure precision, brilliant measure repeatability and allows for automatic measurement [8,12-13]. However, the research on application of coordinate measuring technique for radioactive field has not been reported in literature. This paper was dedicated to

coordinate measurement technique in hot cell by using CMM, which was structural adjustment to adapt hot cell environment. The thickness of plate-type fuel elements, the diameter and ovality of tubular fuel elements, shape dimensions of fuel assemblies, and other dimensions were achieved automatically by means of using coordinates to establish position accurately and sectional measuring with special fixture. The results showed that coordinate measuring technique could be applied in hot cell for post irradiation dimension measurement, which applied to measure different dimensions with a high measure precision of $2\mu\text{m}$.

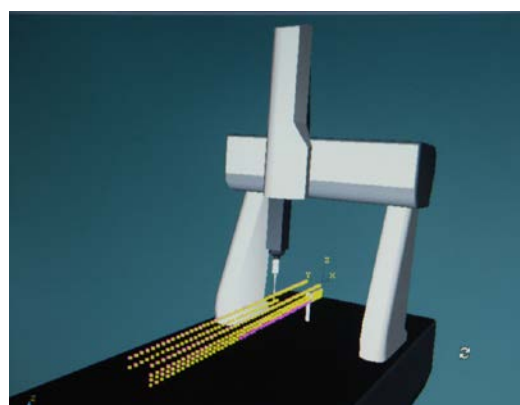
2 CMM

The CMM used in this research is adopted “bridge” structure, which is composed of three axis, X, Y and Z. Each axis has a scale system that indicates the location of the axis. By precisely recording the X, Y and Z coordinates of the target, points are generated which can then be analyzed via regression algorithms for the construction of features. These points are collected by using a probe that is positioned manually by an operator or automatically via direct computer control. According to direct computer control, CMM can be programmed to repeatedly measure identical parts.

The CMM in hot cell as shown in Fig.1 was structural adjustment in three respects: Firstly, the dimensions of each part were adjustment to the size of hot cell and the “bridge” structure materials were selected as high strength stiffness to weight ratio materials, by which can get an enhanced measure precision; Secondly, the grating rulers of three axis and the cable conductors were shielded and installed far away from radioactive materials to reduce the influence of radiation; Thirdly, the CCD cameras were installed in hot cell to present real-time monitoring, as direct observation of measuring process was infeasible in high radiation environment.



a) Machine



b) Software simulation

Fig.1 CMM in hot cell

3 Thickness measurement of Plate-type FE

3.1 Experiment

3.1.1 Distribution of measuring points

Plate-type FE commonly present a certain degree of swelling after irradiation, thus causing dimension change, especially the thickness change. Fig.2 shows the thickness measuring points with a distribution of 20×3 .

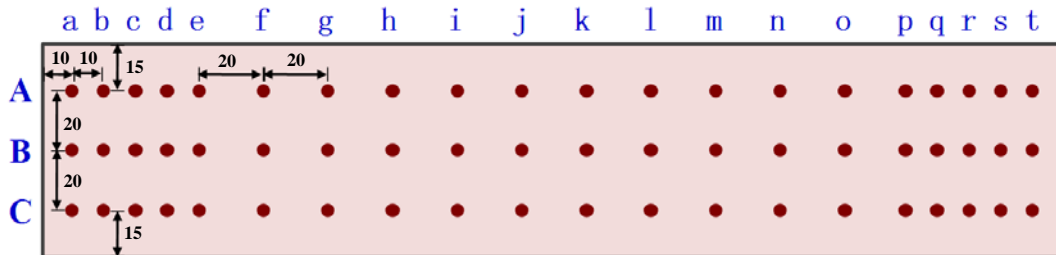


Fig.2 Distribution of thickness measuring points

3.1.2 Fixture

The clamp part of fixture is consisted of four collects, which is uniform distribution (Fig.3). The touch position between fixture and FE is covered with rubber to avoid scratch to FE and buffer holding force.

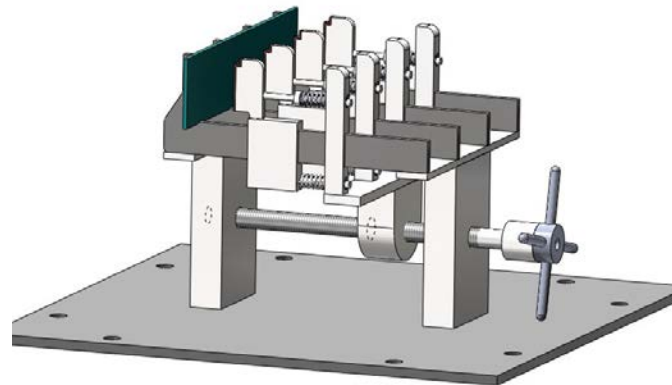
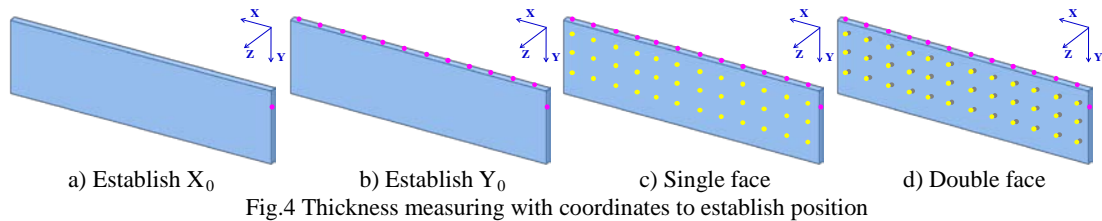


Fig.3 Fixture for plate workpieces

3.1.3 Measure with coordinates to establish position

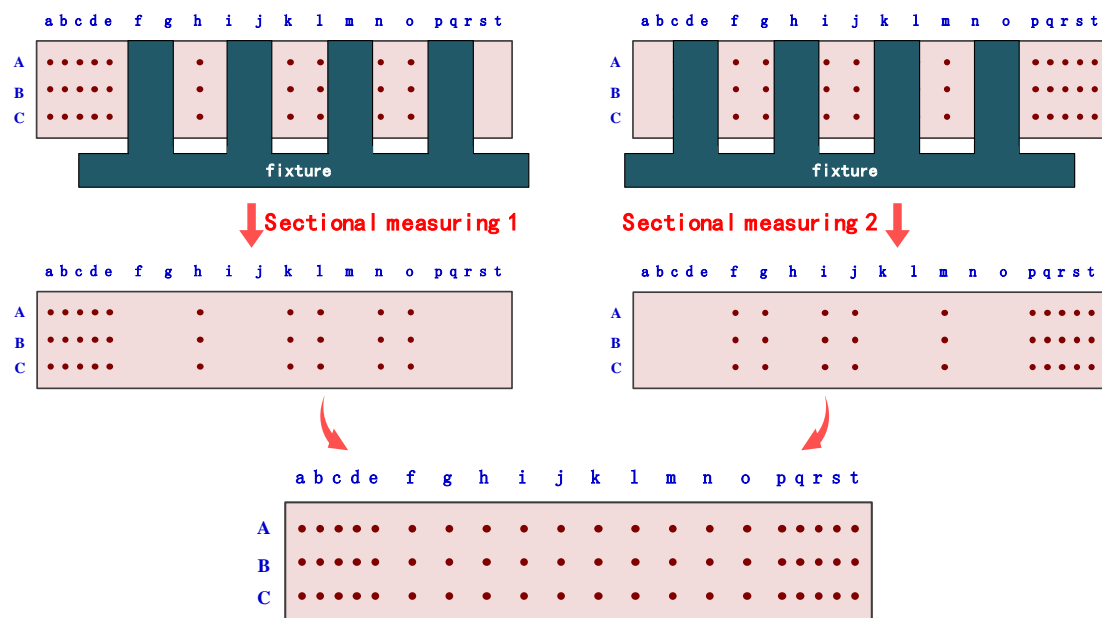
Comparison of the dimension data before and after irradiation can be rationalized according to high precision and repetitiveness for measuring points. Fig.4 illustrates the thickness measuring process with coordinates to establish position accurately. Firstly, the vertex and three edges of plate-type FE can be set as the origin and three axis of coordinate system, from which coordinate system is established on FE. Secondly, run the automatic measure program on computer and the beginning point position of X axis on FE is established (Fig.4a), after which the value of X_0 on FE can be obtained by the order language “obtain” from measure program. Thirdly, establish 20

beginning points of Y_0 on FE (Fig.4b) according to the X value space between these 20 points and X_0 is set, as shown in Fig.2. Fourthly, measure the points on one face (Fig.4c). It is worth noting that the X value and Y value of these points are established from X_0 and Y_0 on FE so that the uniqueness of every point is clear. Finally, the measure points on the other face are obtained in the same way (Fig.4d) and the differences between these Z values are defined as thickness of FE.



3.1.4 Sectional measuring

The plate-type FE should be hold in stable in measuring process to avoid the error due to mechanical vibration. One inevitable result is that some measuring points will be covered by the touch position between fixture and FE. Therefore, sectional measuring will be effective for inaccessible measure points from the first measuring. On the basis of calculation that the space between two neighbor collects can distribute two arranges of measure points at most, two sectional measuring is rational method, as shown in Fig.5.



3.2 Example result

Figure 6 presents the example of measured thickness for plate-type FE. Repeated measure result shows that the changes of X and Y coordinate values were in $1\mu\text{m}$ when repeated

immediately or after clamp again, indicating a repeatability precision of 2 μ m which is double change of coordinate value.

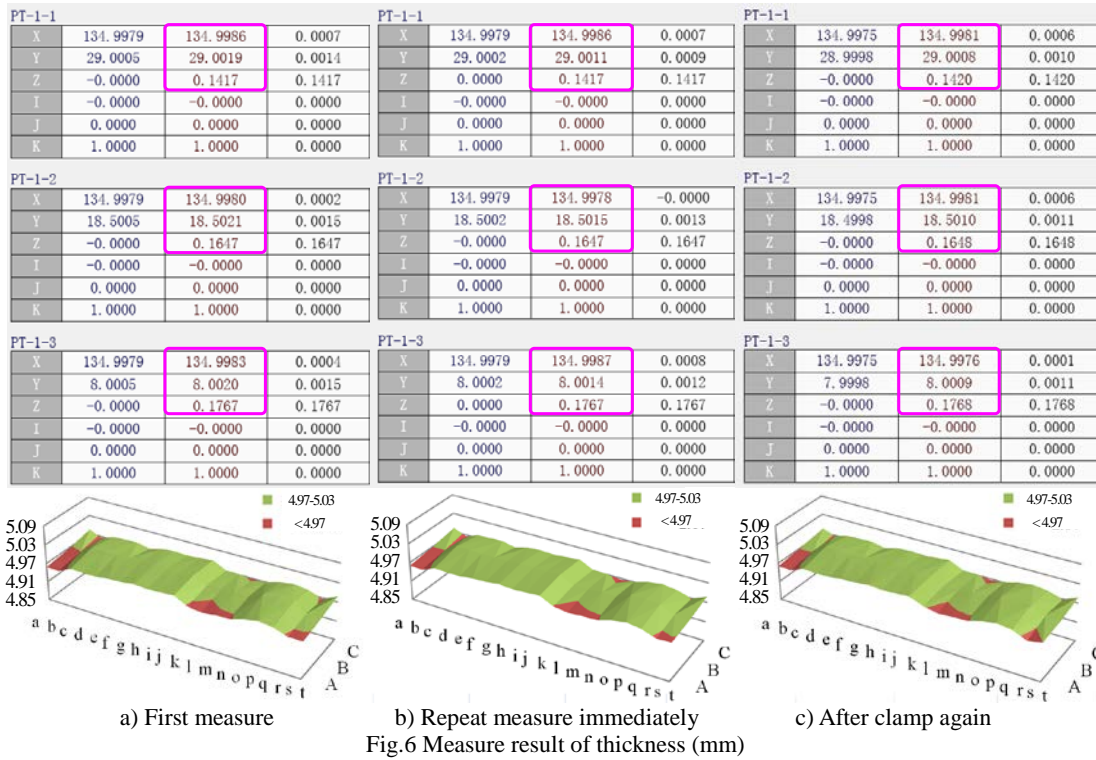


Fig.6 Measure result of thickness (mm)

4 Diameter and ovality measurement of tubular FE

4.1 Experiment

Diameter and ovality change play a great role in dimension change of tubular FE after irradiation. The schematic of tubular FE and fixture is shown in Fig.7, which include an unlock support frame to avoid the deflection of FE.

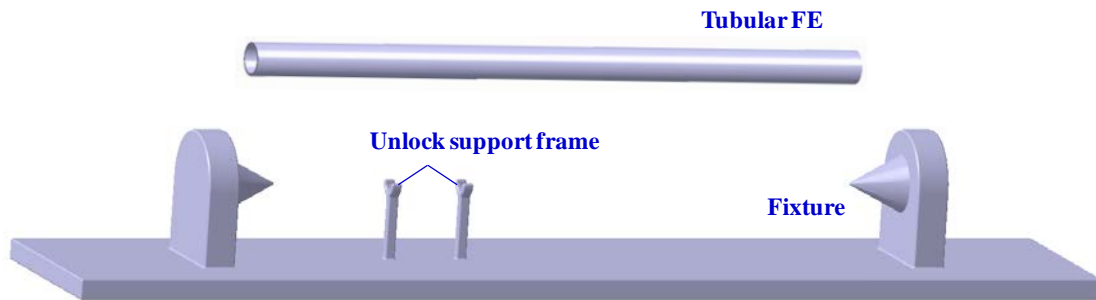
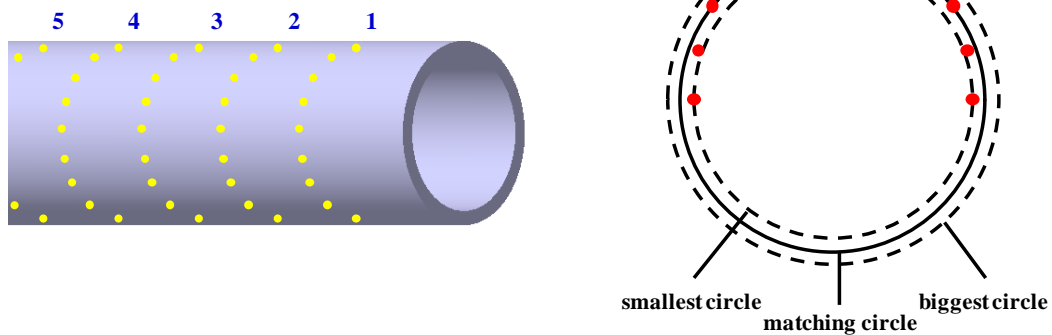


Fig.7 Schematic of tubular FE and fixture

As shown in the schematic of Fig.8, every cross section has a distribution of nine points, which can be synthesized as a semicircle. It is reasonable to generate a matching circle for the calculation of diameter, a biggest circle and a smallest circle for the calculation of ovality according to the difference value between them (Fig.8b).



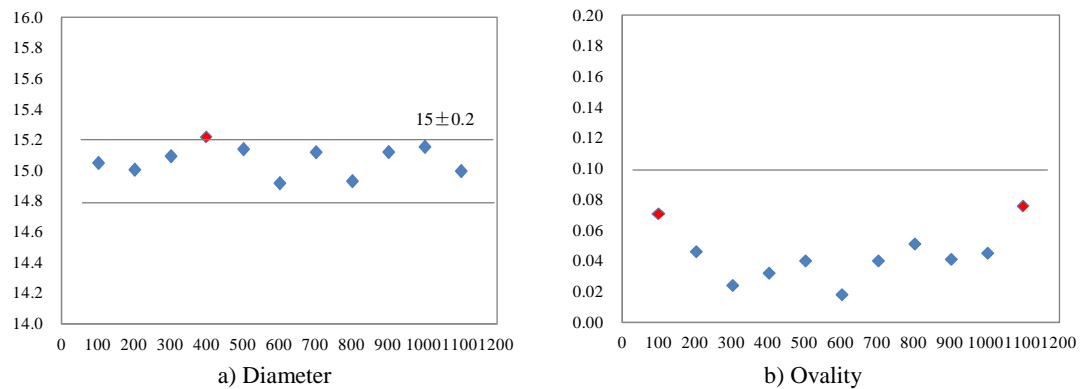
a) Distribution of measuring points

b) Schematic of matching circle

Fig.8 Schematic of diameter and ovality measuring

4.2 Example result

Figure 9 presents the example of measured diameter and ovality for tubular FE, the changes of diameter at different section are $\pm 0.2\text{mm}$ and the ovalities are below 0.1mm .



a) Diameter

b) Ovality

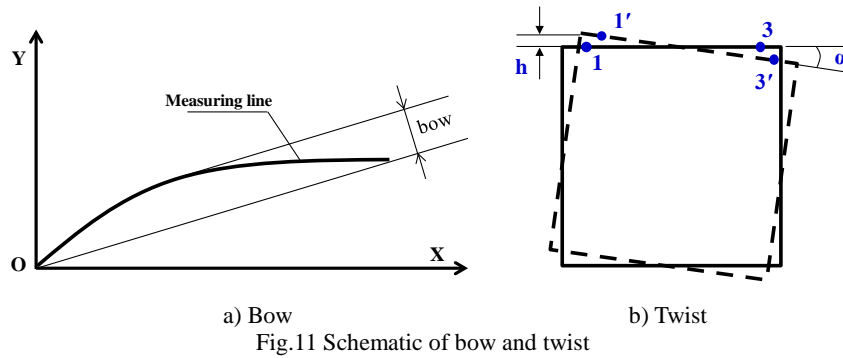
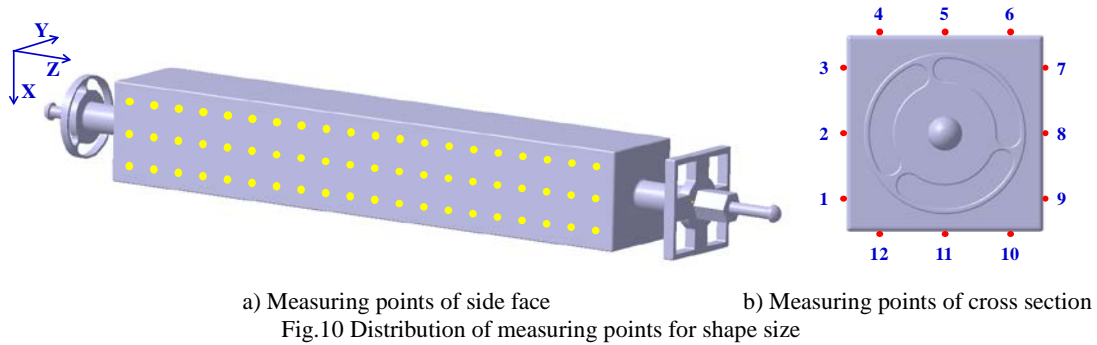
Fig.9 Measured dimension of tubular workpiece (mm)

5 Shape dimension measurement of FA

5.1 Experiment

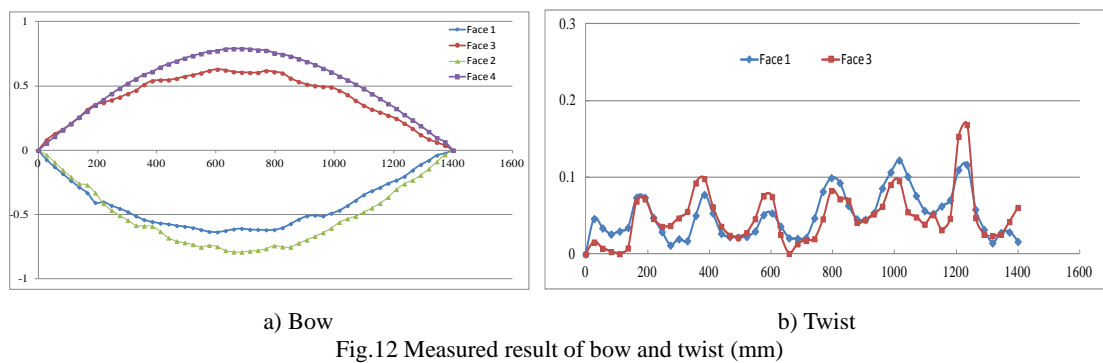
The dimension change, such as change of bow, twist, flatness and perpendicularity, is particularly important for fuel assemblies which are approaching their design life, or indeed operating beyond them. These dimensions can be calculated from the same measuring points. As shown in Fig.10, every side face has a distribution of 3 measuring lines, which include 70 measuring points respectively. The bow of these measuring lines can be understood by calculating the distance from each point to the line, which is matched end to end (Fig.11a). On the other hand, every face also has 70 lines by connecting 3 measuring points in the same face and cross section into a line, such as point 1, 2 and 3. Based on the first line, the face twist is commonly identified by calculating the deflection angle from the other 69 lines to first line (Fig.11b). Besides, the

flatness of each face can be calculated by matching all measuring points in same face, such as the face included line 1,2 and 3; the perpendicularity can be calculated by matching measuring lines in two adjacent faces, such as the line consisted of point 1,2,3 to the other line consisted of point 4,5,6.



5.2 Example result

As presented in Fig.12, the bows of two opposite side faces are in same size level but opposite direction, rather than the twists, which exhibit similar trend for two opposite side faces.



6 Measurement of bubble height

6.1 Experiment

The measurement of bubble (Fig.13) height for fuel element after high temperature bubble test is particularly important for the research of failure behavior in accident condition. Measuring

process is sketched in Fig.14. Firstly, the measuring points are distributed as 10×10 with a separation distance of 1mm controlled by estimated bubble size, as described in Fig.14a. According to the datum plane, which is consisted of measuring points outside the bubble, bubble height can be obtained by calculating the distance from each point to the datum. Subsequently, second measuring points (Fig14b) are also distributed as 10×10 , while the separation distance are reduced as 0.25mm. It is worth mentioning that the area of second measuring points are $\geq 4\text{mm}^2$ and covering the 9 measuring points in first measurement, which include the max bubble height point as centre point. By parity of reasoning, third or fourth measurement can be carried out to get the final bubble height, and the times of measurement are rationalized according to actual measure precision demand.

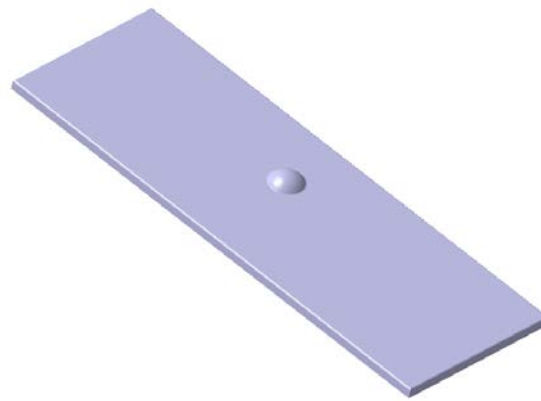


Fig.13 Schematic of bubble on FE

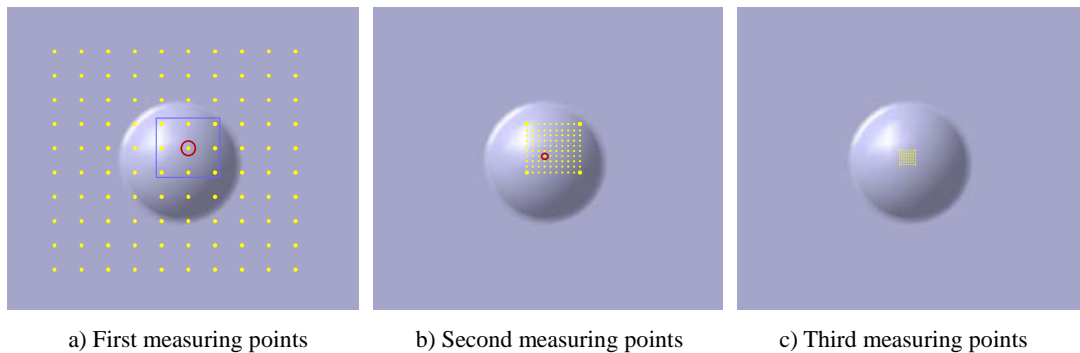
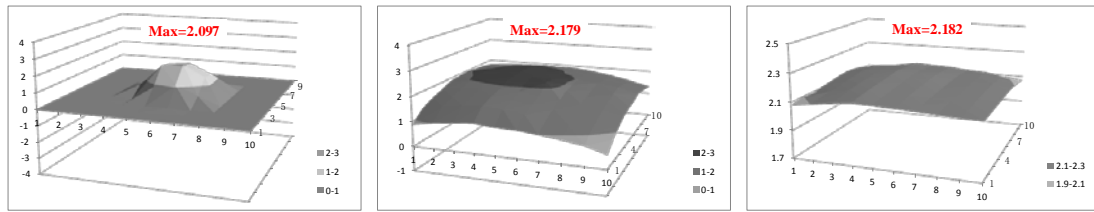


Fig.14 Measuring of bubble height

6.2 Example result

Figure 15 presents the example of measured bubble height for FE, the max bubble height are 2.097mm for first measurement, 2.179mm for second measurement, and 2.182mm for third measurement, showing an increasing trend clearly with measure times. Moreover, the max bubble height of third measurement is only 0.003mm bigger than second one, can rationally represent the final bubble height of FA.



a) First measuring

b) Second measuring

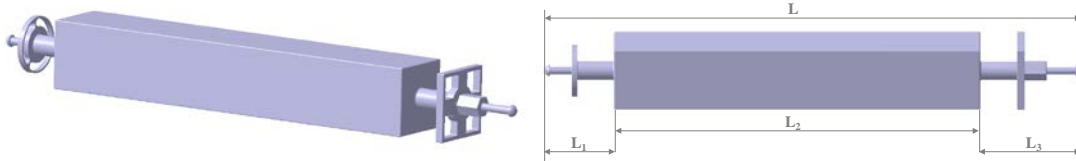
c) Third measuring

Fig.15 Measured result of bubble height

7 Large dimension measurement

7.1 Sectional measuring

It is reasonable to assume that some large dimension measurement, such as the total length of FA, may be beyond the measuring range of CMM. This type of large dimension can be measured by sectional measuring according to structural feature of FA and coordinates to establish position accurately. As sketched in Fig.16, the total length of FA is divided into three independent measurements, namely $L=L_1+L_2+L_3$.



a) FA structure

b) Schematic of sectional measuring

Fig.16 Sectional measuring of length for FA

7.2 Measure with coordinates to establish position

Fig.17 shows the length measurement of L_1 section. Firstly, vertex and three edges of the cuboid structure in FA can be set as the origin and three axis of coordinate system, from which coordinate system is established on FA. Subsequently running the automatic measure program on computer and the beginning point position of X axis and Z axis on FA is established, after which the value of X_0 and Z_0 on FA can be obtained accurately. Thirdly, measure point A,B,C,D on end face and 13 points on spherical face as sketched in Fig.17. It should be mentioned that the X value and Z value of these points are established from X_0 and Z_0 on FA so that the uniqueness of every point is clear, and the difference value between vertex of matched sphere and end face included point A,B,C,D is defined as the length of L_1 section. The length measurement of L_2 and L_3 section are achieved in the same way.

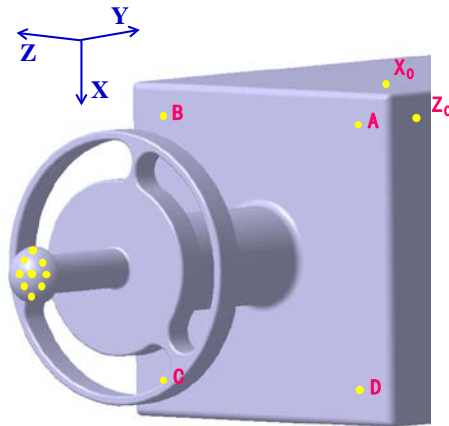


Fig.17 Schematic of measuring points for L₁ section

8 Conclusion

The CMM used in this paper was structural adjustment to adapt hot cell environment and has been successfully applied in hot cell based on measuring technique research, which greatly improve the flexibility, accuracy and reliability of dimensional measuring method in hot cell. The application range of CMM in hot cell include different structural fuel element or fuel assembly, such as plate-type FE, tubular FE and plate-type FA, etc. The automatic measurement involving geometrical dimensions, such as length, thickness and diameter, shape dimensions, such as bow, twist, flatness and perpendicularity, and other dimensions, such as bubble height and large dimension, are achieved by means of using coordinates to establish position accurately and sectional measuring with special fixture, showing the ability of coordinate measuring technique in measuring different dimensions in hot cell with a high measure precision of 2 μ m.

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